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Field strength near the ground at v.h.f. and u.h.f. : theoretical dependence on polarisation

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

FIELD STRENGTH NEAR THE GROUND AT V.H.F. AND U.H.F.: THEORETICAL DEPENDENCE ON POLARIZATION

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FIELD STRENGTH NEAR THE GROUND AT V.H.F. AND U.H.F.: THEORETICAL DEPENDENCE ON POLARIZATION

SUMMARY

Under ideal conditions, vertically-polarized v.h.f. and u.h.f. transmissions would give much higher field strengths close to the ground than horizontally-polarized transmissions. Although the theoretical difference between the two polarizations could be as much as 30 dB at ground level, it decreases rapidly with height and is less than 3 dB at a height of one wavelength.

1. INTRODUCTION

At v.h.f. and u.h.f. the field strength above ground is the vector sum of direct and ground-reflected waves. Since the reflection coefficient of the ground is approximately −1 for both vertical polarization (v.p.) and horizontal polarization (h.p.) for the range of reflection angles which occur in practice, it is reasonable to assume that the resultant field strength well above the ground is almost independent of polarization. Near the ground, i.e. at heights of less than one wavelength, the field is more critically dependent on the reflection coefficient, and the two polarizations behave rather differently because the coefficients deviate from −1 by different amounts.

The theoretical difference between the two polarizations is discussed here for the idealized situation which arises when the point of observation is situated above flat ground of infinite extent. The results described may be very different in practice because of surface roughness and because obstacles on the propagation path may modify the polarization of the incident wave; some examples of these effects are described elsewhere.[1]

2. THEORETICAL CONSIDERATIONS

Fig. 1 shows a transmitting aerial T and a receiving aerial R above uniform flat ground of infinite extent. Although this ideal situation is seldom encountered in practice, the theory stated here is approximately correct provided that the ground plane satisfies the Rayleigh criterion, and is uniform, over the first Fresnel zone.* The point T may represent an actual transmitting aerial or a virtual source on a diffracting edge.

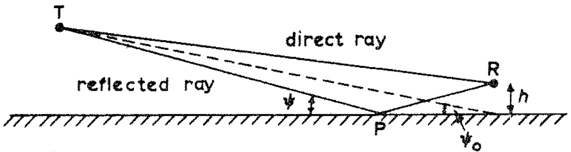

Fig. 1 - Transmitting and receiving aerials over flat ground

The wave arriving at the receiving aerial is the resultant of direct and ground-reflected waves; the latter is retarded in phase by an amount corresponding to the path difference TPR-TR and is modified by the Fresnel plane-wave reflection coefficient.[2,3]

Provided the reflection angle ψ is less than 10° the Fresnel reflection coefficients may be written in the form

$$\rho_V \simeq \frac{K_r\psi - \alpha}{K_r\psi + \alpha} \qquad (1)$$

$$\rho_H \simeq \frac{\psi - \alpha}{\psi + \alpha} \qquad (2)$$

where ψ is in radians, K_r is the complex relative permittivity of the ground and $\alpha = (K_r - 1)^{\frac{1}{2}}$. Complex relative permittivity is defined as

$$K_r = \epsilon_r - \mathrm{j}1{\cdot}8 \times 10^4 \sigma/f$$

where

ϵ_r is the relative permittivity (dielectric constant)
σ is the conductivity in mhos/m
f is the frequency in MHz

In the United Kingdom ground constants lie within the range given in Table 1.

TABLE 1

Range of Ground Constants in the United Kingdom

	Dielectric constant ϵ_r	Conductivity (mhos/m) σ
'Very good' ground	30	2×10^{-2}
'Poor' ground	5	10^{-3}

---

* The first Fresnel zone on the ground is defined as the area enclosed by the locus of a point P′ on the ground such that the path length TP′R exceeds TPR (Fig. 1) by $\lambda/2$, where λ is the wavelength. It is a long narrow ellipse. The Rayleigh criterion is satisfied for an angle ψ (Fig. 1) if departures from the mean ground level are less than $\pm\lambda/16 \sin\psi$.

At 45 MHz K_r is equal to 30−j8 and 5−j0·4 for 'very good' and 'poor' ground respectively. The real part of K_r predominates and at higher frequencies the imaginary part becomes even smaller. In all that follows K_r will therefore be assumed to be real and equal to the dielectric constant, since this results in a considerable simplification.

If K_r is real and equal to ϵ_r, ρ_V and ρ_H are also real and have the values shown in Fig. 2. Both ρ_V and ρ_H are equal to -1 when $\psi = 0$, but ρ_V departs from -1 much more rapidly than ρ_H as ψ increases.

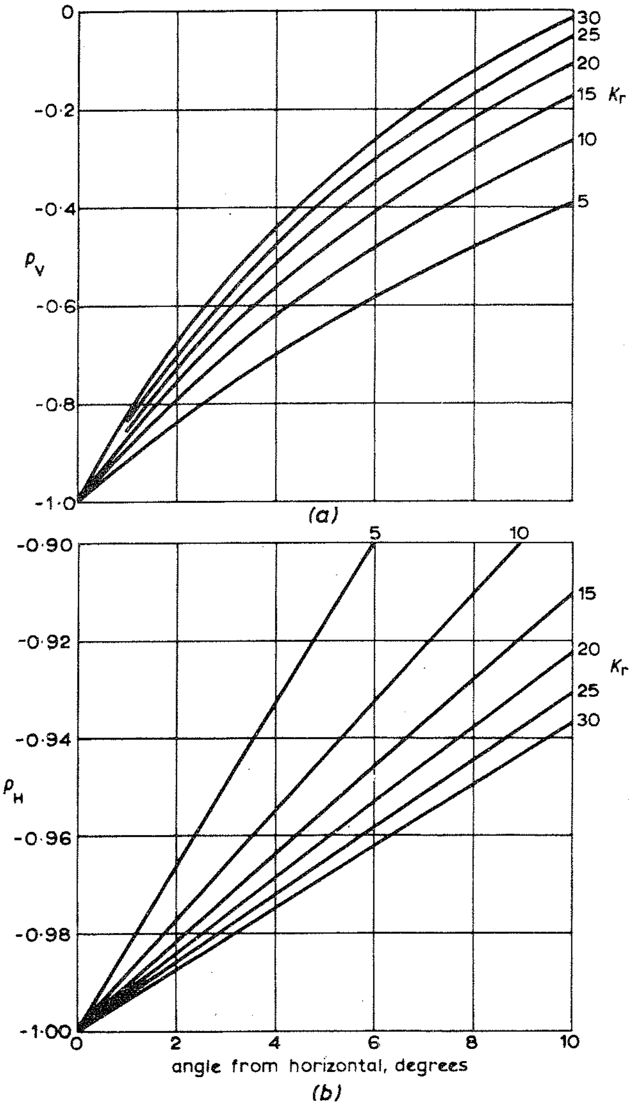

Fig. 2 - Plane-wave reflection coefficients

(*a*) Vertical polarization (*b*) Horizontal polarization
K_r is equal to the dielectric constant of the ground

The resultant field at R, for both v.p. and h.p. is given by

$$E = E_0\left[1 + \rho e^{-i\theta}\right] \qquad (3)$$

where E_0 is the free-space field strength, ρ is the appropriate reflection coefficient and θ is the phase retardation corresponding to the path difference TPR-TR (Fig. 1). For a distant source, θ is related to the height h of the observed field by $\theta \simeq 4\pi\psi_0 h/\lambda$, where ψ_0 is the reflection angle for zero height.

Fig. 3 shows the relationship between the direct and reflected waves in vector form. When the receiving aerial is on the ground, θ is zero and the vectors representing the direct and reflected waves are coincident; their resultant is then proportional to $1 + \rho$. When the receiving aerial is raised the resultant describes one of the loci shown by broken lines in Fig. 3. It will be seen that, although the resultant for v.p. is initially very much greater than the resultant for h.p., the difference between them diminishes rapidly as the receiving aerial is raised and θ increases.

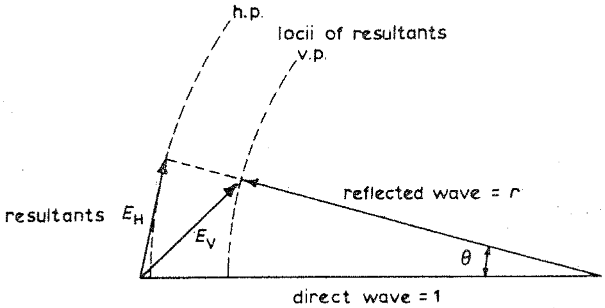

Fig. 3 - Vector diagram showing direct and reflected waves

As an example, Fig. 4(*a*) shows how the resultant field strength varies with height above ground when the wave is incident at 1° to the horizontal. At heights greater than one wavelength the v.p. and h.p. curves are similar and exhibit the well-known linear height-gain variation. Below one wavelength the h.p. field strength falls much more rapidly than the v.p. field strength. Fig. 4(*b*) shows the ratios between the v.p. and h.p. field strengths as a function of height.

The v.p./h.p. field-strength ratio at ground level is

$$\frac{E_V}{E_H} = \frac{1 + \rho_V}{1 + \rho_H} = \frac{\psi + \alpha}{K_r\psi + \alpha}K_r \qquad (4)$$

At grazing incidence, when ψ tends to zero, this is simply equal to K_r, i.e. in the dielectric constant ϵ_r. Thus, for 'very good' ground, the ratio can in theory be as much as 30 dB. Fig. 5 shows that the ratio at ground level does not vary to any great extent with the angle of arrival of the incident wave.

Considering next the field above ground, values of θ for which E_V and E_H have specified ratios may be derived from Fig. 3. It will be seen that

$$E_V{}^2 = 1 + r^2 - 2r\cos\theta$$

where r (equal to $-\rho_V$) is the length of the vector representing the reflected wave. Also

$$E_H \approx 2\sin\frac{\theta}{2}$$

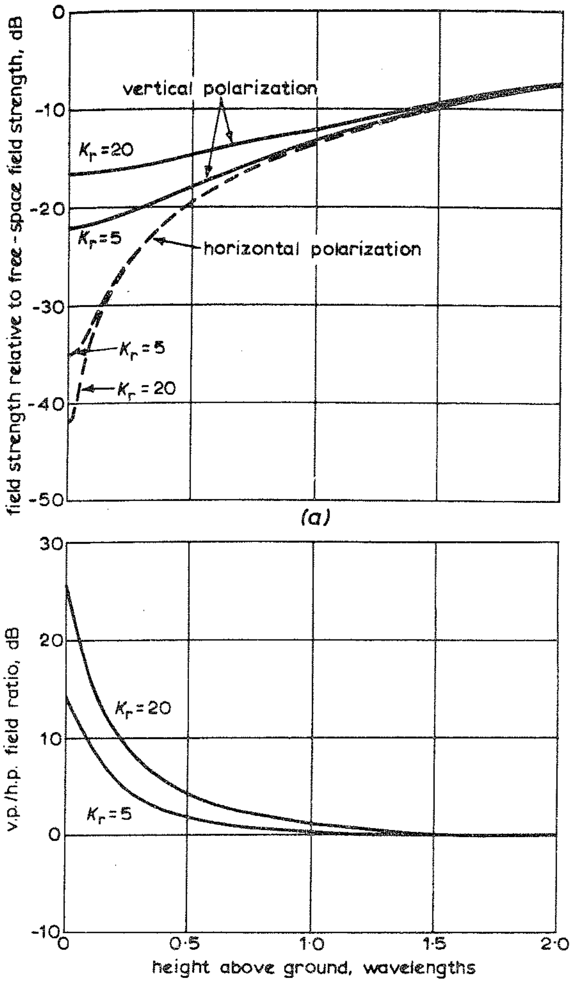

Fig. 4 - Field strength and v.p./h.p. ratio as a function of height above ground

Angle of arrival 1°

K_r is equal to the dielectric constant of the ground

except when θ is very small, since $\rho_H \approx -1$. From this it follows that E_V exceeds E_H by only 3 dB when

$$\cos\theta = \frac{3-r^2}{2(2-r)} = \frac{3-\rho_V{}^2}{2(2+\rho_V)} \qquad (5)$$

Values of θ for which the v.p./h.p. ratio is 3 dB are shown in Fig. 6(*a*) for reflection angles up to 10°, while Fig. 6(*b*) shows the heights where this ratio applies. As the height increases the difference between the two field strengths diminishes, rapidly at first, and becomes zero when

$$\cos\theta = \tfrac{1}{2}(1-\rho_V);$$

these values of θ and the corresponding heights are also shown in Fig. 6. E_V and E_H remain approximately equal for a considerable range of heights above this level and will differ significantly at greater heights only if the path difference between the direct and ground-reflected waves approximates to an integral number of wavelengths.

It should be noted that Fig. 6(*b*) may be in error if the actual reflection angle ψ differs from ψ_0 by more than 10%, or if the aerial heights are more than 10 times the distance between them. Although Fig. 6(*b*) applies with negligible error to most situations which arise in practice, it should be used with caution when the distance between the aerials is small. This restriction does not apply to Fig. 6(*a*).

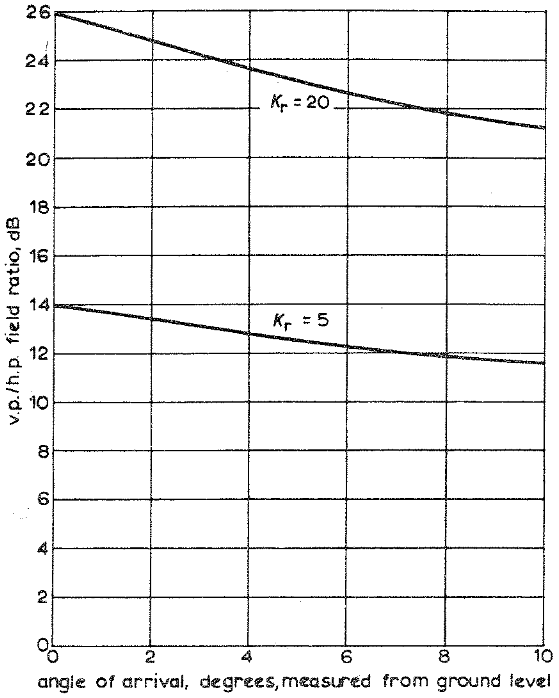

Fig. 5 - Limiting value of v.p./h.p. ratio at ground level

K_r is equal to the dielectric constant of the ground

3. CONCLUSIONS

Under ideal conditions the field strength close to the ground at v.h.f. and u.h.f. would be expected to be greater with a vertically-polarized incident wave than with a horizontally-polarized wave. At ground level the theoretical ratio between the two polarizations is approximately equal to the dielectric constant of the ground and may be as much as 30 dB. The ratio decreases rapidly with height and is less than 3 dB for a considerable range of height above one wavelength.

Because the superiority of vertical polarization is restricted to heights below one wavelength, it is of practical use only at v.h.f., where the wavelength is relatively large. The use of v.p. may then be advantageous for equipment operated close to the ground; Band II car radios and portable Band I and Band II television and sound receivers would come within the category. Measurements described elsewhere[1] have confirmed that there is no significant difference between v.p. and h.p. at heights above one wavelength, but they have also

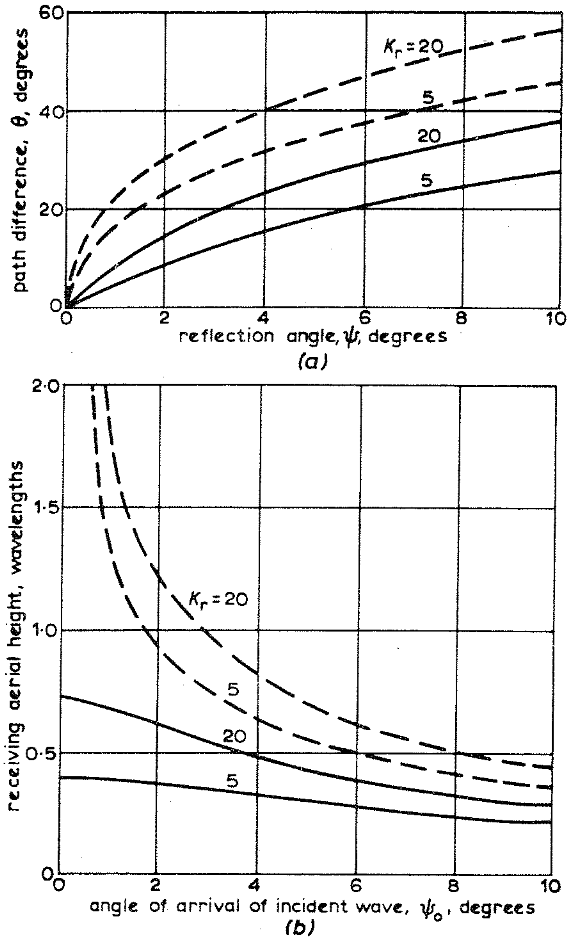

Fig. 6 - Path difference and receiving aerial height for specified v.p./h.p. field ratios

——— v.p./h.p. ratio 3 dB
- - - - - v.p./h.p. ratio 0 dB
K_r is equal to the dielectric constant of the ground

indicated that the difference close to the ground is considerably less than the theoretical difference calculated here for ideal conditions. Thus, the advantage to be gained in practice by using v.p. (or by adding a v.p. component to an h.p. transmission) may be somewhat less than the idealized theory contained in this report would suggest.

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